Methods Of And Arrangements For Buffering Digital Optical Signals

Cross-Reference To Related Application

This application claims priority of European Patent Application No. 00301170.7, which was filed on February 15, 2000.

5   Field Of The Invention

The present invention relates to the field of optical buffers for buffering digital optical signals.

Background Of The Invention

In Optical Time Division Multiplexing (OTDM) systems long optical fiber loops,
10   sometimes with a length in the order of some kilometers, are used to provide a delay or buffer for lower rate input optical signals before they are transmitted as interleaved output optical signals on one output line. The disadvantages of such systems are mainly their physical dimensions and complexity.

Summary

15   The problems of prior art arrangements are overcome according to the principles of the invention by buffering digital optical signals without using long optical fiber loops.
In particular, a digital optical signal having a predetermined digital level is buffered, during at least a predetermined retention time, by inputting the optical signal to an optical input of a semiconductor laser element and injecting an injection current to the
20   semiconductor laser element to establish an optical gain process in the semiconductor laser element. The injection current has an amplitude such that the optical gain process and an optical absorption process within the semiconductor laser element outweigh one another longer than the retention time in order to keep the digital optical signal on the predetermined digital level during the retention time.

25   According to one illustrative embodiment, a semiconductor laser element is used instead of a long optical fiber loop. Such a buffer arrangement is physically smaller than the long optical fiber loop arrangement used in the prior art. The laser parameters are chosen such that the digital optical signal is trapped between reflective facets of the semiconductor laser element and retains its data characteristics during at least a
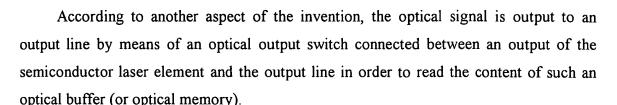30   predetermined retention time.

According to another aspect of the invention, the optical signal is output to an output line by means of an optical output switch connected between an output of the semiconductor laser element and the output line in order to read the content of such an optical buffer (or optical memory).

5   In another illustrative embodiment of the invention, time division multiplexing of a plurality of digital optical signals, each having a predetermined digital level, is accomplished by inputting each of the optical signals to an optical input of one of a plurality of semiconductor laser elements and injecting a distinct injection current to each of the semiconductor laser elements to establish an optical gain process in each of the

10   semiconductor laser elements. Each injection current has an amplitude such that the optical gain process and an optical absorption process within each of the semiconductor laser elements outweigh one another longer than a predetermined retention time in order to keep each of the digital optical signals on each of the predetermined digital levels during the retention time. Each of the optical signals are consecutively output to one

15   output line in consecutive time frames by means of a plurality of optical output switches, each one of the plurality of output switches being connected between an output of one of the semiconductor laser elements and the output line.

According to another illustrative embodiment, an arrangement for buffering, during at least a predetermined retention time, a digital optical signal having a predetermined

20   digital level comprises a semiconductor laser element with an optical input for receiving the optical signal and a current source connected to the semiconductor laser element and arranged to inject an injection current to the semiconductor laser element to establish an optical gain process in the semiconductor laser element. The injection current has an amplitude such that the optical gain process and an optical absorption process within the

25   semiconductor laser element outweigh one another longer than the retention time in order to keep the digital optical signal on the predetermined digital level during the retention time. Again, such an arrangement is physically smaller than the long optical fiber loop arrangements of the prior art and is more flexible.

According to another aspect of the invention, a controller is connected to the

30   current source to provide a current control signal to the current source to control an amplitude of the injection current. Additionally, in order to be sure that the optical gain

process and the optical absorption process within the semiconductor laser element outweigh one another, the value of the injection current to the semiconductor laser element can be continuously adjusted by using a feedback control system. In such an arrangement, an optical detector is arranged to detect optical power content of the

5   semiconductor laser element and to provide a feedback signal to the controller, the controller being arranged to generate the current control signal in dependence on the feedback signal. The arrangement may also comprise an optical output switch connected between an output of the semiconductor laser element and an output line, and connected to the controller to receive an output switch control signal to control outputting of the

10   optical signal to the output line. In order to be able to control the moment in time that a digital optical signal enters the buffer arrangement, the arrangement may comprise an optical input switch connected to the input of the semiconductor laser element, and connected to the controller to receive an input switch control signal to control inputting of the optical signal to the semiconductor laser element.

15   **Brief Description Of The Drawings**

A more complete understanding of the present invention may be obtained from consideration of the following detailed description of the invention in conjunction with the drawing, with like elements referenced with like reference numerals, in which:

Figure 1 schematically shows an optical multiplex arrangement according to the

20   prior art;

Figure 2 schematically shows how four different optical signals may be interleaved in a multiplex arrangement according to the prior art;

Figure 3 shows a multiplex arrangement in accordance with the present invention; and

25   Figure 4 schematically shows a semiconductor laser element according to the prior art.

Detailed Description Of The Embodiments

In the multiplex arrangement shown in figure 1, a multiplexer MX receives four different input signals from four different buffers BF(i), (i = 0, 1, 2, ..., I; in the example

30   of the figures I = 3 but I may have any other suitable integer value $\geq$ 2). The buffers BF(i) receive respective input signals $S_{in}(i)$. For timing purposes, these input signals $S_{in}(i)$ may

be switched by optical switches $SW_{in}(i)$. These switches $SW_{in}(i)$ are, preferably, controlled by a controller not shown in figure 1.

In existing multiplex arrangements, the buffers $BF(i)$ comprise long optical fiber loops of which the length may be in the order of some kilometres, to provide a delay for

5   the input signals $S_{in}(i)$, the delay being different for different input signals $S_{in}(i)$.

The output signals of the buffers $BF(i)$ are indicated in figure 1 by $S_{in}^*(i)$.

Figure 2 shows an example of the timing of the output signals $S_{in}^*(i)$ of the buffers $BF(i)$, as well as of output signal S_o of the multiplexer MX. The buffers $BF(i)$ are designed such that the input signals $S_{in}(i)$ are delayed to such an extent that signals $S_{in}^*(i)$ do

10   not overlap and that multiplexer MX only need to switch all signals $S_{in}^*(i)$ to its output line to generate output signal S_o comprising four consecutive output signals $S_o^*(i)$. The timing of figure 2 suggests that multiplexer MX introduces no further time delays. However, this may well be the case.

Since the buffers $BF(i)$ according to the prior art are relatively large and introduce

15   complexity to the multiplex arrangement, the present invention proposes to use semiconductor laser elements as optical buffer elements. These elements are physically smaller and more flexible than the buffers according to the prior art. Below, it will be explained how this can be achieved.

Figure 4 schematically shows a well known semiconductor laser element 1. The

20   laser element 1 comprises a cathode 3 and an anode 5. Between the cathode 3 and the anode 5 there is a semiconductor layer 7 comprising at least a pn-junction as is known to persons skilled in the art. Any simple or more complex semiconductor layer arrangement in layer 7 may be used in the present invention. The cathode 3 is connected to a wire 4, whereas the anode 5 is connected to a wire 6. In use, an electrical current is supplied to

25   the laser element 1 through these wires 4, 6 by a current source (or voltage source). The laser element 1 comprises (cleaved) semireflective ends 7, 9. In use, the semireflective ends 7, 9 reflect emitted photons back into the bulk of the semiconductor material where, by reabsorption, the rate of photon emission is increased, resulting in photon light amplification. If the current through wires 4, 6 to the semiconductor material is increased,

30   a threshold is reached at which the photon density is too great to be contained by the optical cavity defined by the volume of the semiconductor material of layer 7. Then,
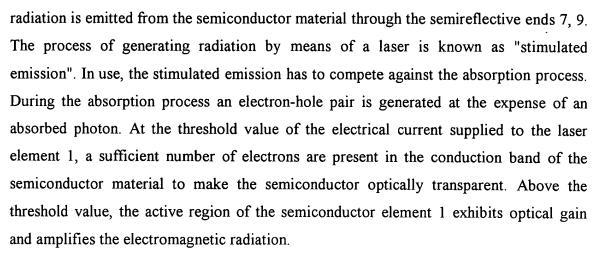
radiation is emitted from the semiconductor material through the semireflective ends 7, 9. The process of generating radiation by means of a laser is known as "stimulated emission". In use, the stimulated emission has to compete against the absorption process. During the absorption process an electron-hole pair is generated at the expense of an

5 absorbed photon. At the threshold value of the electrical current supplied to the laser element 1, a sufficient number of electrons are present in the conduction band of the semiconductor material to make the semiconductor optically transparent. Above the threshold value, the active region of the semiconductor element 1 exhibits optical gain and amplifies the electromagnetic radiation.

10 Due to the optical feedback by the semireflective facets 7, 9, that form a Fabry-Perot cavity, the number of photons travelling perpendicular to the semireflective ends 7, 9 increase when the electrical current is high enough to satisfy the condition of net stimulated emission. Some of the photons are lost through the semireflective ends 7, 9 and some get scattered or absorbed in the cavity. Below the threshold value of the

15 electrical current, the loss exceeds gain and the stimulated emission cannot sustain a steady supply of photons. At the threshold value of the electrical current, however, gain equals loss and stimulated emission begins to dominate. Over a narrow electrical current range close to the threshold current value, the gain increases by several orders of magnitude and above the threshold value of the electrical current, the laser output (i.e. the

20 radiation output) increases almost linearly.

At the threshold region, i.e., when optical gain equals loss, ideally any optical signal present within the cavity would simply travel to and fro between the reflective ends 7, 9 and retain its characteristics. The inventor of the present invention has found that this property can be applied to use a semiconductor laser element 1 as a memory for

25 optical signals.

This can be done in an arrangement in which the semiconductor laser element 1 as shown in figure 4 is connected as radiation amplifier element as is known to persons skilled in the art. In such an amplifier arrangement, the semireflective ends 7, 9 are both connected to optical fibers one of which being used as optical input and the other one of

30 which being used as optical output.

An example of the proposed arrangement is shown in figure 3. Figure 3 shows a multiplex arrangement for four different input signals $S_{in}(i)$. The input signals $S_{in}(i)$ are received by optical switches SW_{in}. The optical switches $SW_{in}(i)$ are controlled by control signals $SWCON_{in}(i)$ generated by a controller CON.

5   The output signals of the switches $SW_{in}(i)$ are connected to directive filters $F_{in}(i)$. The outputs of the directional filters $F_{in}(i)$ are connected to optical inputs of semiconductor laser elements SLE(i). Current sources I(i) supply electrical current to the semiconductor laser elements SLE(i). The current sources I(i) receive control signals ICON(i) from the controller CON.

10   The current sources I(i) may be substituted by voltage sources if required. The current sources I(i) need not be physically separated. One current source arranged to supply as many different electrical currents as there are semiconductor laser elements SLE(i) may be used instead.

Optionally, detectors D(i) may be placed on one of the semireflective ends of the

15   semiconductor elements SLE(i). These detectors D(i) generate electrical feedback signals FB(i) supplied to the controller CON for purposes explained below.

The optical outputs of the semiconductor laser elements SLE(i) are connected to directional filters $F_o(i)$. The outputs of the directional filters $F_o(i)$ are connected to optical output switches $SW_o(i)$. The outputs of optical switches $SW_o(i)$ are connected to one

20   single optical output line for supplying output signal S_o. The output optical switches $SW_o(i)$ are controlled by control signals $SWCON_o(i)$ generated by controller CON.

In the arrangement of figure 3, each of the semiconductor laser elements SLE(i) can be used as a memory unit for storing an optical signal ideally for an infinite power-on time, with a write or update cycle and a read cycle.

25   The optical input signals $S_{in}(i)$ are lower speed signals, e.g., of 2.5 Gb/s. Each of the optical input signals $S_{in}(i)$ are optical bit type of signals, i.e., they will have a value either representing a digital 1 or a digital 0. The control signals $SWCON_{in}(i)$ are generated by a clock in the controller CON synchronized to control a selected switch $SW_{in}(i)$. The selected switch $SW_{in}(i)$ switches on and allows the optical signal $S_{in}(i)$ to enter the

30   semiconductor laser element SLE(i).

The directional filters $F_{in}(i)$ are arranged such that they allow the signals $S_{in}(i)$ to travel in one direction into semiconductor laser elements SLE(i) only. Such directional filters are known to persons skilled in the art and need no further explanation here. Moreover, they may be located elsewhere: input directional filter $F_{in}(i)$ may be located at the opposite side of $SW_{in}(i)$ whereas output directional filter $F_{o}(i)$ may be located at the opposite side of $SW_{o}(i)$.

During a write process of a certain semiconductor laser element SLE(i), the respective input switch $SW_{in}(i)$ is switched on whereas the respective output switch $SW_{o}(i)$ is switched off. Before starting such a write process a memory clear process is necessary. This is due to the following reason: assume the power of an optical signal to be written is low and the power of a previous optical signal was high, then the new value of the optical signal within the semiconductor laser element SLE(i) will also be high if the signal present in the semiconductor element SLE(i) is not removed. Hence, a memory clear process in which the power of the optical signal present in de semiconductor laser element SLE(i) is forced to be low is necessary. This can, e.g., be achieved by turning off the electrical current supplied by current source I(i) concerned for a certain short period of time.

During the period of memorizing the optical signal in the semiconductor laser element SLE(i) the respective output switch $SW_{o}(i)$ is controlled by its control signal $SWCON_{o}(i)$ to be in its off-state, i.e. it prevents the optical signal from leaving the semiconductor laser element SLE(i) concerned. So, the optical signal is, then, reflected between the semireflective ends 7, 9 of the semiconductor laser element SLE(i). The amount of reflectivity of the semireflective ends 7, 9 may be specially designed to have an optimal value. It may be designed for a predetermined threshold value of the electrical current supplied by current source I(i). Then, when the electrical current supplied by current source I(i) is close to the threshold current region, the optical gain due to optical feedback caused by the reflectivity of the semireflective ends 7, 9, and due to the received optical signal $S_{in}(i)$ and the value of the electrical current received from current source I(i), just equals the loss due to the absorption process during which an electron-hole pair is generated at the expense of an absorbed photon.

During reading out of the semiconductor elements SLE(i) in the multiplex arrangement shown, each of the output switches $SW_o(i)$ is consecutively switched on to provide output signal S_o, e.g., as shown in figure 2. The output switches $SW_o(i)$ can be controlled by the control signals $SWCON_o(i)$ such that output signal S_o has a higher data

5   rate than the input signals $S_{in}(i)$.

Above, an optical multiplexing technique using semiconductor laser elements SLE(i) as memory units for optical bits of information is explained. Of course, the concept shown in figure 3 can be expanded to a plurality of output lines to provide a byte multiplexing technique.

10   The basic element of the present invention is a semiconductor laser element SLE(i) used as an optical memory unit for an optical bit of information. As explained above, the electrical current supplied by the current source I(i) is chosen such that the optical gain in the semiconductor element SLE(i) substantially equals the absorption of photons in the laser element during memorizing of the optical bit of information. For a predetermined

15   minimum retention time of memorizing the optical bit of information, the reflectivity of the semireflective ends 7, 9 of the semiconductor laser element SLE(i) and the electrical current value can be optimized. Then, one will be sure that, although an optical signal within the semiconductor laser element SLE(i) may steadily change its value due to a small imbalance between optical gain and absorption of photons, the retention time will

20   still exceed the required minimum value. Alternatively, a feedback control system for the electrical current may be used. In such a feedback control system, the detector D(i) detects the optical power of the optical signal present within the semiconductor laser element SLE(i). The feedback signal FB(i) is fed back to controller CON which is arranged to generate current source control signal ICON(i) such that current source I(i)

25   adjusts its electrical current supplied to the semiconductor laser element SLE(i) such that the optical power remains constant (within a small delta change allowed). Such a feedback control is synchronized with the memory write process such that it starts after the memory write process.

It is observed that the arrangements given above are only given by way of example

30   only. For instance, in the arrangement of figure 3, the input switches $SW_{in}(i)$ may be

omitted when the optical input signals $S_{in}(i)$ already have a proper timing, i.e., the timing of signals $S_{in}^*(i)$ as shown in figure 2.

Moreover, the controller CON is shown as a single unit. It may be implemented as a software driven (micro)processor arrangement, including necessary equipment like memory (RAM, ROM, EEPROM, etc.), keyboard, mouse, monitor, etc., as is evident to persons skilled in the art. However, it may also be implemented using digital and/or analog circuits, as the case may be. Moreover, it may be implemented as a plurality of processors communicating with one another and arranged for performing subtasks. Thus, where in the claims "a controller" is claimed for performing tasks as specified, this is intended to include all practical embodiments evident to persons skilled in the art.

Accordingly, various modifications to the illustrative embodiments will be apparent to those skilled in the art and are contemplated by the teachings herein.